MEMORANDUM

March 9, 2005

To: Derrik Spoelman and Rita Neill, MCRM
From: Brad Johnston, SCS Engineers
Subject: Results of Soil Vapor Survey, Cave Creek Landfills

Pursuant to your request, SCS has performed additional research regarding the implications of the results of the soil vapor survey performed at the Cave Creek Landfills. This information is provided below.

LEACHATE AND LANDFILL GAS CHARACTERISTICS

Typical leachate and landfill gas (LFG) characteristics are discussed below. However, the mineralogy of soils and groundwater quality at a specific location can influence the effects of leachate and LFG on groundwater.

Leachate

Leachate generated from a municipal solid waste landfill typically contains high concentrations of soluble organic and inorganic constituents, such as high total suspended solids (TDS), biochemical oxygen demand (BOD), total organic carbon (TOC), chemical oxygen demand (COD), organic nitrogen, ammonia nitrogen, nitrate, alkalinity, total hardness, calcium, magnesium, potassium, sodium, chloride, sulfate, metals, and others. Other chemicals may be present, such as pesticides and solvents. The actual composition is dependent upon many variables that affect the solubility of the constituents and their ability to enter the liquid phase.

Landfill Gas

The composition of LFG, by volume, is typically about 45 to 58 percent methane; 35 to 45 percent carbon dioxide (CO_2); less than 1 to 5 percent each of oxygen, nitrogen, and hydrogen; 1 to 5 percent water vapor; and less than 1 to 3 percent trace constituents. Methane is relatively insoluble in water, but can act as a reducing agent in chemical reactions with soil constituents, potentially mobilizing soluble metals. Highly soluble CO_2 can decrease water pH, and through acid-base reactions with soil constituents, increase the concentrations of bicarbonate alkalinity, calcium, magnesium, and metals in water. Oxygen and nitrogen are not produced as LFG is generated, but is usually introduced by air intrusion into the landfill, the LFG control system, or LFG sample train. Hydrogen is usually present in LFG only during aerobic decomposition and the earliest anaerobic decomposition stages. Higher temperatures within landfills due to decomposition of organic matter allow LFG to become saturated with water vapor. (SWANA 1993)

Although LFG does not contain non-volatile compounds, acid-base and oxygen-reduction chemical reactions between the LFG and soil and water can mobilize inorganic compounds, allowing soluble compounds to be transferred into water. This can cause complications when trying to evaluate whether impacts to groundwater are associated with leachate or LFG. A study looking at correlations between LFG and total VOC concentrations in the LFG did not find a correlation with chloride, sodium or sulfate concentrations, indicating a possible method of distinguishing between LFG and leachate impacts to groundwater (Kerfoot et. al. 2004).

Many different kinds of trace compounds can be found in LFG, depending on the composition of the landfill wastes. LFG typically contains a much larger potential mass of contamination than does leachate (Prosser et. al. 1999). The EPA estimated default concentration of total non-methane organic compounds (NMOCs) in LFG is 595 parts per million by volume (ppmv), of which 110 ppmv are hazardous air pollutants (HAPs) (EPA 1998). NMOCs, which include HAPs and volatile organic compounds (VOCs), can be transported in a vapor phase or liquid phase to groundwater underlying a landfill.

Degradation of VOCs can change the makeup of the compounds originally present in the LFG. Dichloro- compounds are typically the first products produced in the subsurface from degradation of the primary chlorinated solvents (Nielsen 1991). The VOC transformation products vinyl chloride, 1,1-dichloroethane (DCA), and 1,1-dichloroethene (DCE) appear to be most susceptible to early absorption into soil water and volatilization into LFG, and thus may indicate a LFG excursion front (Clister et. al.).

CONTAMINANT TRANSPORT MECHANISMS

Leachate Migration

Leachate passing through landfill wastes can obtain contaminants directly from waste materials and/or from LFG. The amount of leachate produced at a landfill is related to the amount of precipitation the landfill receives; arid landfills typically generate much lower volumes of leachate than landfills in areas with higher levels of precipitation. The leachate can migrate out of a landfill, particularly if it is unlined, and infiltrate to groundwater beneath the landfill. Depth to groundwater, permeability of the soil, composition of the soil, and other soil physical properties can affect movement of the leachate through the vadose zone.

Landfill Gas Vapor Phase Transport

Groundwater can be impacted by direct contact with LFG that has migrated in vapor phase, which allows NMOCs in the LFG to be absorbed into the groundwater. Vapors can migrate away from a landfill by the processes of diffusion and pressure gradient flow. During diffusion, individual compounds in the LFG equilibrate by moving from areas of higher to lower concentrations, thus typically away from the landfill. Pressure gradient or advective flow causes LFG to move from higher to lower pressure areas. Decomposition in the landfill mass typically causes an increase in pressure; therefore, vapor flow will be away from the landfill. Convective flow may be considered separately from pressure gradient flow, consisting of flow caused by the density of the LFG compounds or temperature differentials.

These dispersal mechanisms can allow LFG to impact groundwater upgradient and crossgradient from a landfill, as well as downgradient. Migration of LFG can be affected by temperature; soil physical properties, bacteria, moisture content, and organic content; types, concentrations, and physical properties of compounds present in the LFG; barometric pressure changes; and other factors.

Landfill Gas Liquid Phase Transport

Contaminants in LFG migrating away from a landfill may be transferred to a liquid phase and then be transported by infiltration across the capillary fringe to groundwater. This can be a result of infiltration of meteoric water or by drainage of soil water under falling water table conditions. Fluctuating water levels allow contaminated water to be dispersed through clean water and the capillary zone, enhancing vapor transport through the capillary fringe (Nielsen 1991). Two methods of transferring compounds in LFG to the liquid phase are as follows:

- LFG in the unsaturated vadose zone may be in contact with water in the soil pores or infiltrating water from precipitation, irrigation, or other sources, allowing NMOCs to transfer to the liquid phase. Contaminants in LFG may adsorb onto soil solids, which may then be available to transfer to water in soil pores or infiltrating through the vadose zone.

- Because temperatures outside the landfill tend to be lower than inside the landfill, the temperature change undergone by LFG during migration away from the landfill can cause water vapor in the LFG to condense in the soil. NMOCs in the LFG can then be transferred to the condensed water vapor.

EXAMPLE LANDFILL STUDIES

Landfill, Tucson, Arizona

The unlined landfill was operated between the 1960s and 1980s. Precipitation in this area is about 12 inches of rain annually. Soil beneath the landfill consisted of sand and silt with lenses of gravel and clay. Depth to groundwater was approximately 240 below ground surface (bgs). The refuse was relatively dry and there was no evidence that leachate generation has occurred. Soil beneath the landfill was also relatively dry (5 to 20 percent by weight). Tetrachloroethene (PCE) and other halogenated VOCs were detected in concentrations that were higher in the vadose zone beneath the landfill than in the refuse. A groundwater contamination plume extended approximately 1,500 feet downgradient of the landfill. Concentrations of PCE ranged from approximately 4 to 570 micrograms per liter (ug/L) in gas samples collected from the vadose zone beneath the landfill and approximately 5 to 50 ug/L in groundwater. The median net infiltration rate for arid sites under natural land use has been calculated as approximately 3 percent of annual precipitation. Evidence of leachate migration was not identified, such as increased concentrations of TDS and chlorides.

A transport model was developed to back calculate transport parameters needed to reproduce observed groundwater concentrations from measured vadose zone soil gas concentrations. The results indicated that soil gas concentrations could produce groundwater concentrations exceeding maximum contaminant levels (MCLs) due to vapor transport mechanisms, even in the absence of significant vertical soil water movement. (Walter et. al. 2003)

Elsinore MSW Landfill, Elsinore, California

Small volumes of LFG (approximately 0.075 cubic meters per second) were produced at this small arid landfill (less than 11 inches of annual rainfall and $1.5x10^6$ cubic meters airspace).

However, VOCs contamination in the groundwater appeared to be due to migration of LFG from the landfill. Groundwater contamination by VOCs occurred upgradient of the landfill. Trichloroethene (TCE; 4 ug/L), 1,1-DCA (53 ug/L), PCE (9 ug/L), vinyl chloride (2 ug/L), benzene (6 ug/L), and other trace VOCs were detected in groundwater samples from a deep groundwater monitoring well located about 56 feet north of the landfill fill limits. Implementation of LFG extraction wells and LFG management has significantly reduced or eliminated LFG migration at the landfill. (Clister et. al.)

Landfill, Los Angeles, California

Groundwater was at a depth of 180 to 290 feet bgs, and was influenced by seasonal artificial recharge at spreading grounds upgradient of the landfill. The saturated and unsaturated zones consisted of cobbles. VOCs and increased alkalinity were detected in landfill groundwater monitoring wells located upgradient, downgradient, and crossgradient. The highest concentrations of VOCs typically occurred in the 2nd or 3rd quarter samples, which generally coincided with the highest annual groundwater levels. LFG was determined to be the source of VOC contamination in the groundwater; concentrations decreased after upgrading the LFG collection system. (Kerfoot et. al. 2004)

CAVE CREEK LANDFILLS

Groundwater beneath the landfills has been impacted by VOCs, namely TCE, DCE, and toluene. In order to determine whether the landfills are the source of these VOCs in groundwater, the following information may be considered:

- Depth to groundwater: Given the relatively large depth to groundwater (reportedly up to 700 feet), the low precipitation in this area, and the resulting relatively small amount of leachate produced, it is probably not likely that leachate has impacted groundwater.

- Soil conditions below the landfill: If high permeability soils (sand, gravel, cobbles) comprise the entire soil column above groundwater, such conditions would favor the migration of LFG and/or leachate through soils.

- Landfill conditions: The unlined portions of the landfills indicate that LFG and leachate could migrate from the landfills into surrounding soils. The relatively long period of time since waste disposal began increases the distances and amounts of contamination that could have migrated with leachate and/or LFG.

- Leachate: Potentially useful data includes amount generated, and analytical results for VOCs, metals, and inorganics. Is there any evidence at all that leachate is being produced in the landfill? Has any leachate been collected and analyzed from the lined portion of the New Landfill?

- Landfill Gas: Potentially useful data includes analytical results for VOCs, pressure conditions, operation and date of installation of collection system. Is the atmosphere in the landfill under pressure (which would indicate migration of LFG away from the landfill)? Is there a similarity between compounds in LFG and groundwater, or potential chemical reaction products in groundwater? Is there data available from before and after the LFG collection system was operational (e.g., has there been any improvements in groundwater quality since the system has been operating)?

- Groundwater: Potentially useful data includes analytical results for VOCs, metals, and inorganics for impacted and background conditions. This information can be used to compare the presence and concentrations of key compounds (such as chloride, sodium, carbonate, bicarbonate, mass of NMOCs) in LFG and groundwater to evaluate whether leachate or LFG could be impacting groundwater quality.

- Soil vapor: Data from the recently-completed soil vapor survey can be compared to LFG, leachate, and groundwater chemistry.

- Land Uses Around the Landfill: Because the landfill is located in an area where there is little to no commercial or industrial development, an off-site source of contamination does not appear likely.

It should be noted that the absolute values of compounds detected during soil vapor surveys performed at different times are usually not comparable; however, data collected using the same soil vapor survey methodology, but at different times, can be compared qualitatively (ASTM 1992).

RECOMMENDATIONS

Groundwater beneath the landfills has been impacted by VOCs, namely TCE, DCE, and toluene at concentrations ranging up to 15 ug/L. Based on the lack of other potential sources of contamination in the vicinity of the landfills, one or both of the landfills could be the source of this contamination. Although groundwater is very deep at the landfill site, because of the length of time that the landfills have been operating, the unlined condition of the landfills, and the presence of very permeable soils beneath the landfills, there is a potential that LFG (and less likely leachate) could have migrated from the landfill to impact groundwater.

To further investigate whether LFG (or leachate) from the landfill(s) is the source of the VOCs detected in the groundwater beneath the landfills, the following information should be evaluated:

- Previous groundwater sample analyses should be assembled to show the complete laboratory analytical results.

- Groundwater samples should be analyzed for VOCs, metals, and inorganics for both background and impacted conditions.

- The existing analytical results from the well being used for background conditions shows that groundwater at this location appears to be impacted. LFG can migrate upgradient relative to groundwater flow direction. Therefore, this well may not represent true background conditions. If a new upgradient monitoring well is considered, its location should be sufficiently upgradient of the site to avoid such influences.

- Data from LFG sampling and monitoring should be assembled to show the complete laboratory analytical results and pressure conditions. The LFG should be analyzed for NMOCs to identify the compounds present.

The above data for LFG, soil vapor, and groundwater should be compared to evaluate whether there are similarities between the compounds present, or whether chemical reaction products could account for the compounds identified in the groundwater. Any groundwater data available from before and after the LFG collection system was operational should be compared to evaluate whether there has been any improvement in groundwater quality since the system has been operating.

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